NREL/ORNL/DOE Distributed Power System Integration R&D

"Fast Response, Load-Matching Hybrid Fuel Cell"

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EPRI PEAC

Quarterly Review Meeting

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Project Overview

- This project integrates ultra-capacitor and PEM fuel cell technologies to create a “fast response, load-matching, hybrid fuel cell”
- NREL Project Manager Tom Basso, PEAC Team T. Key, T. Geist, D. Nastasi, ESMA Ultra Capacitors and DCH-Enable Fuel Cell
- System size is 3kW, configured for four different applications or modes of operation.
- Objective is to establish performance potential as grid-tied hybrid distributed resource

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Plans for 2001 (Base Year)

- Complete testing of ultra-caps and topical report by July 2001 (draft sent to NREL, Tom Basso)
- Complete testing of PEM fuel cell and report by August 2001
- Report system performance results Oct 2001
  - Design, specifications and evaluation
  - Ragone plots results with and without storage
  - Demonstrate operations from standby mode and as battery replacement in a UPS (EPRI funded tasks)

3 kW PEM Fuel Cell System

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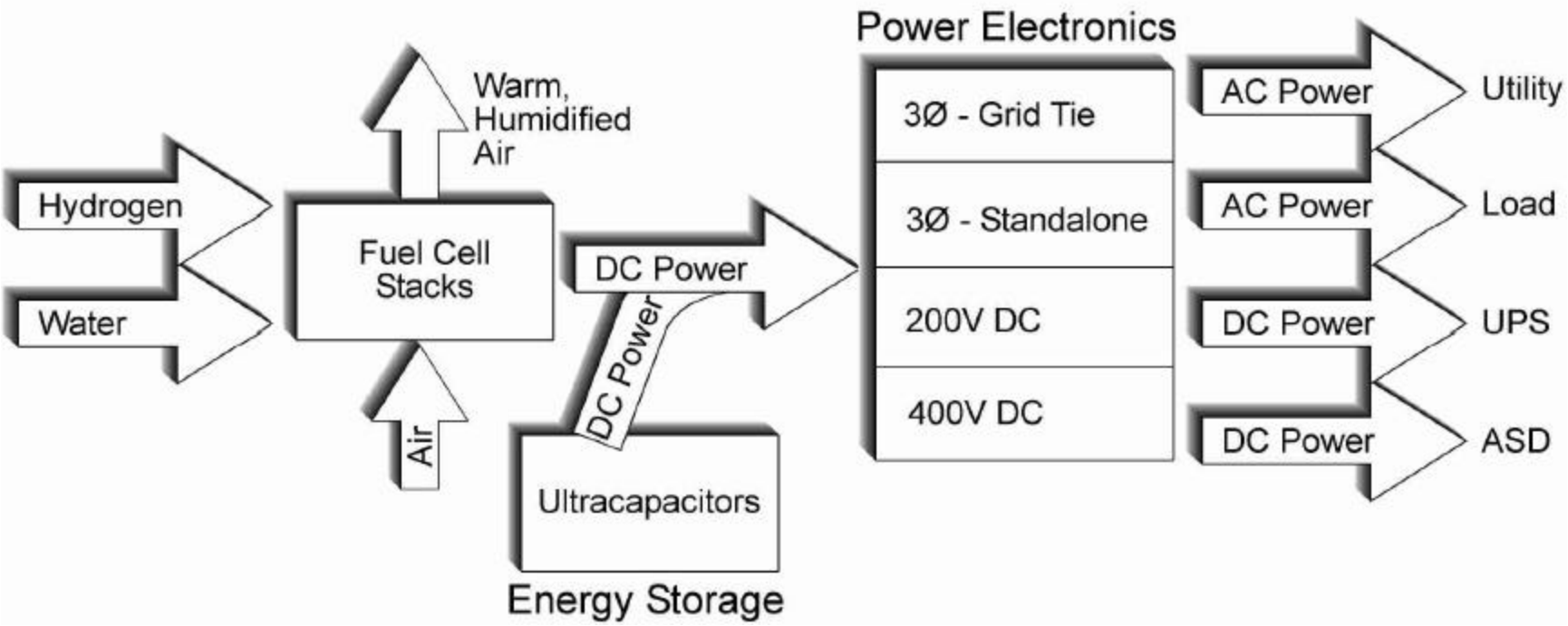
Schematic of Hybrid



- 3-kW fuel cell system designed robust response

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Topical Report – Double Layer Electro-Chemical Capacitors

- Overview of storage technology with cost/ performance of storage systems compared
- Reviewed 18 Companies, 2 US and 16 Overseas
- Sizes from 10 Joule to 166 k Joule
- Claims verified by testing of two leading manufactures
- Parameters evaluated: 1) capacity with load and temperature, 2) equivalent series resistance, and 3) life-cycle.

Energy Stored vs. Power Available

- Comparison by Ragone Plots
- Power Density in kW/kg
- Energy Density in kJ/kg

where:
1kJ = .28 W-Hr

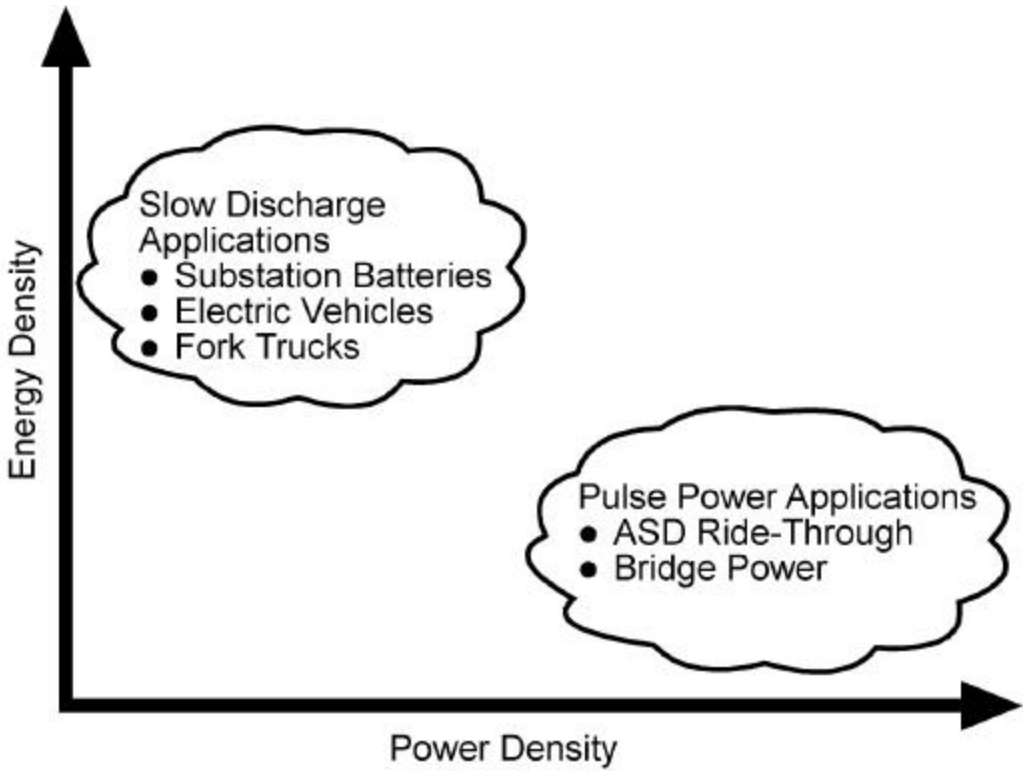
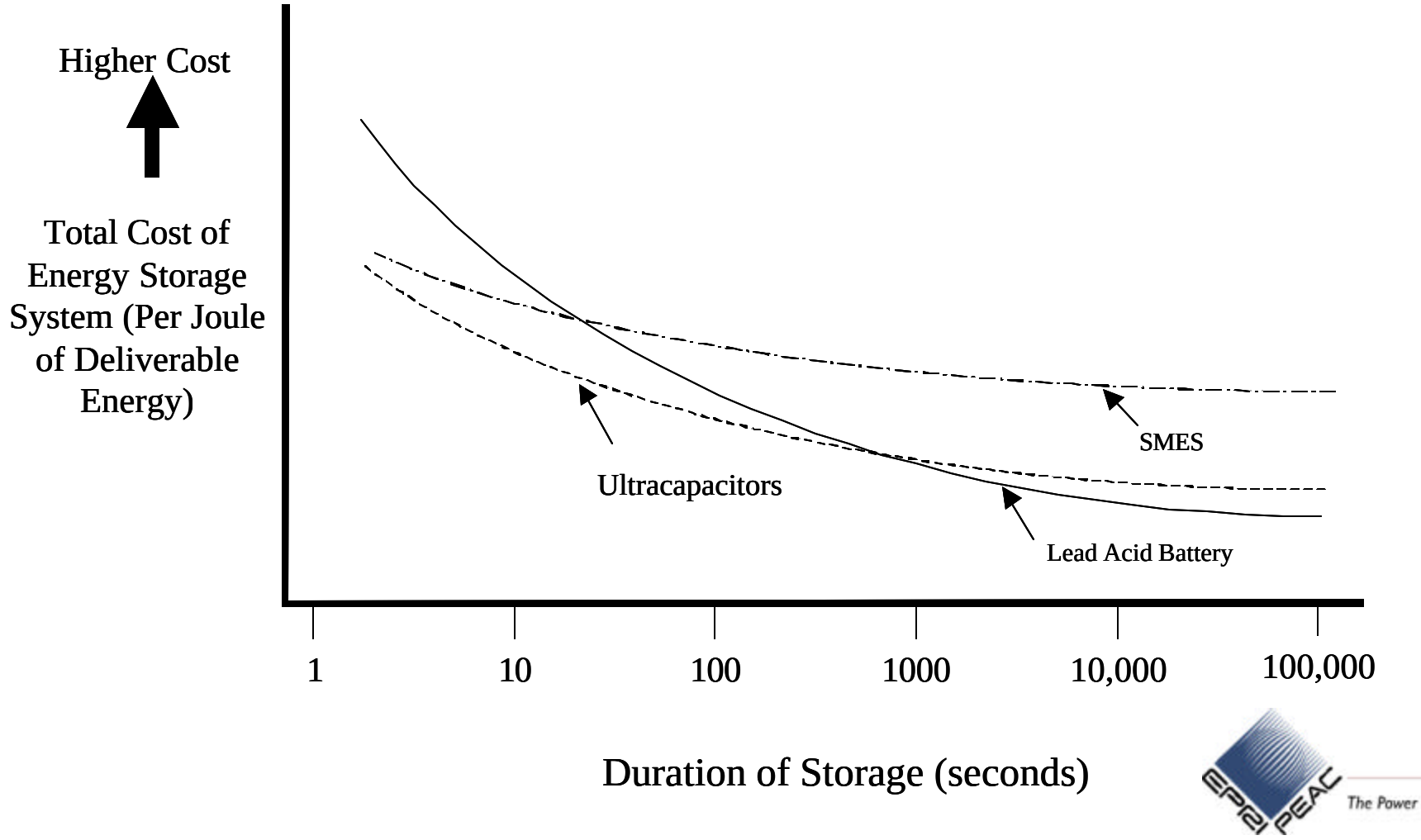


Table 1. Comparison of some key energy-storage technologies

Energy-Storage Technology Type	*Energy Density (WH/kg)*	*Power Density (W/kg)*	*Commercial Availability*
Batteries:			
Lead Acid	35	300	Very mature and readily available
Nickel Cadmium	35	200	Mature and available
Lithium-Ion	90	180	Available
Nickel Hydride	59	200	Available
Zinc-Air	350	60-225	Emerging – very promising
Aluminum-Air	400	10	Emerging – very promising
Sodium Chloride	90	150	Available
Sodium Sulfur	170	260	Available
Zinc Bromine	70	100	Available
Ultracapacitors (electrochemical capacitors)	1-15	2,000-10,000	Commercial Now for PQ but Improved products in 1-5 years for longer duration applications
Advanced Flywheels (steel and composite)	10-100	1,000-10,000	PQ Products Available Now, Long Duration Products Emerging
Superconducting Magnetic Energy Storage (SMES)	62	300-1,000	PQ Products Available Now, Longer Duration Products in Development

Hypothetical crossover points where SMES and ultra-capacitors become less expensive than battery-storage systems



Comparison of Storage Options

Parameter	Batteries	Ultra-capacitors	Flywheels
Efficiency	70-90%	90%	90%
Power Range (W)	5 kW – 10 MW	5-100 kW	1 kW – 10 MW
Energy Range (J)	0.1-600 MJ	1 kJ-10 MJ	1-15 MJ
Cycle Life	2,000	**100,000+**	10,000
Charge Time	Hours	Seconds – minutes	Minutes
Technology Status	Mature	Available	Available
Capital Cost ($/kJ)	$0.2-1.5	$5.0-20	$0.3-2

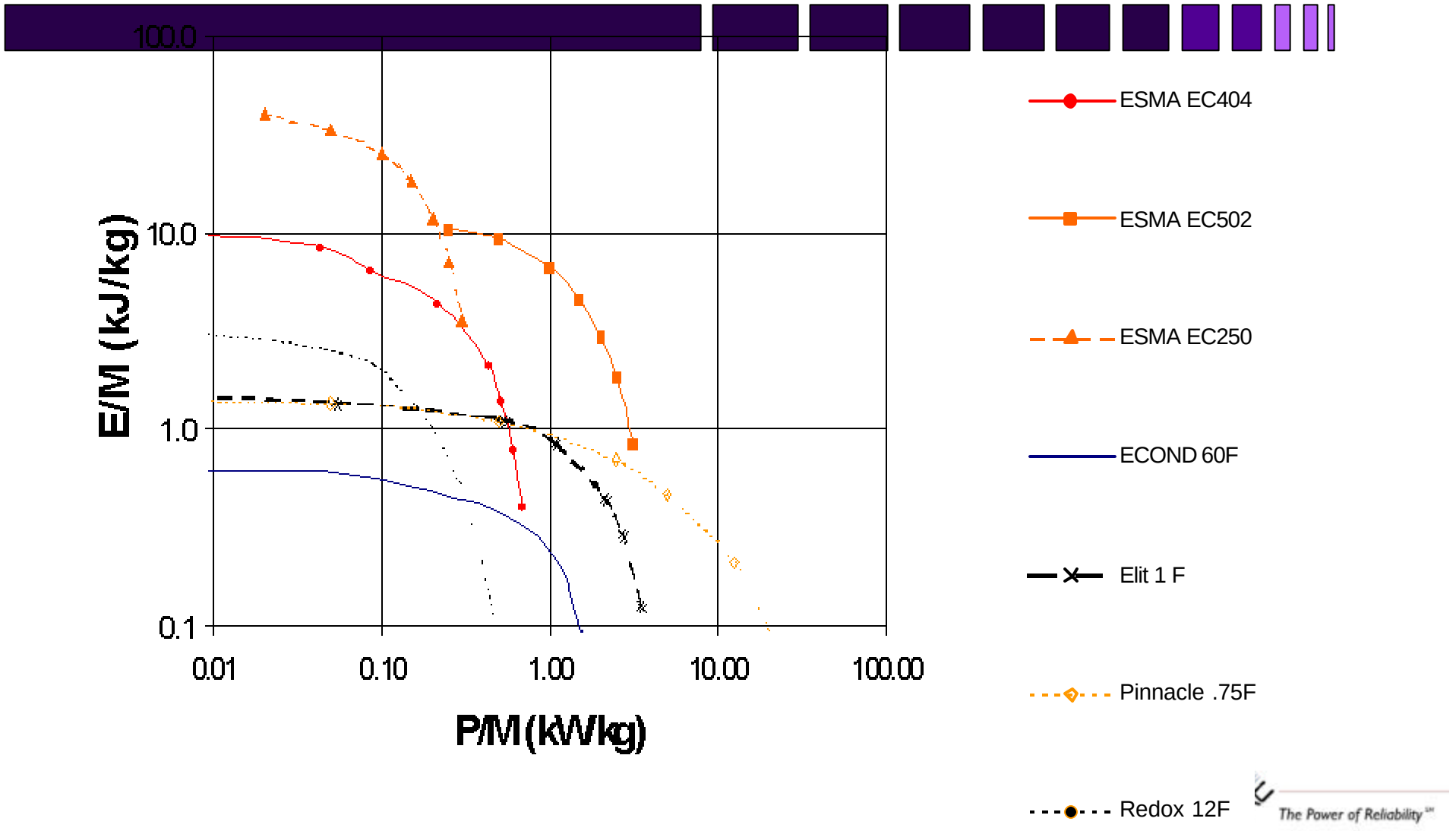
Cost comparison of electrochemical capacitors (commercially available 5- to 10-V capacitors having the largest available capacitance)

Type	*$/Farad*
Electrochemical (Projected)	0.25 - 5
Carbon EC – Commercial	1 - 20
Aluminum Electrolytic	100 - 300
Carbon EC - Military	300 - 700
Tantalum Wet-Slug	8,000 - 13,000

Table 2. Listing of manufacturers of double layer electrochemical capacitors

Company	*Capacitance(F)*	*Voltage (V)*	*Energy (kJ)*
Asahi Glass	240	2.5	1
Asahi Glass	4,300	2.5	13
PCOND	85	28	34
PCOND	25	64	51
ELIT	50	31	24
ELIT	0.5	450	50
ELIT	0.5	359	30
ESMA	130,000	1.3	166
ESMA	32,000	1.4	41
ESMA	3,200	1.4	3
Evans	.56	10	2.8
Evans	0.033	25	0.01
Isuzu/Fuji	100	14	10
Maxwell	2,700	2.3	7
Matsushita	470	2.3	1
Matsushita	1,500	2.3	4
NEC	500	5.5	7
NEC	470	15	53

Ragone plots for sample with 1-kJ ratings



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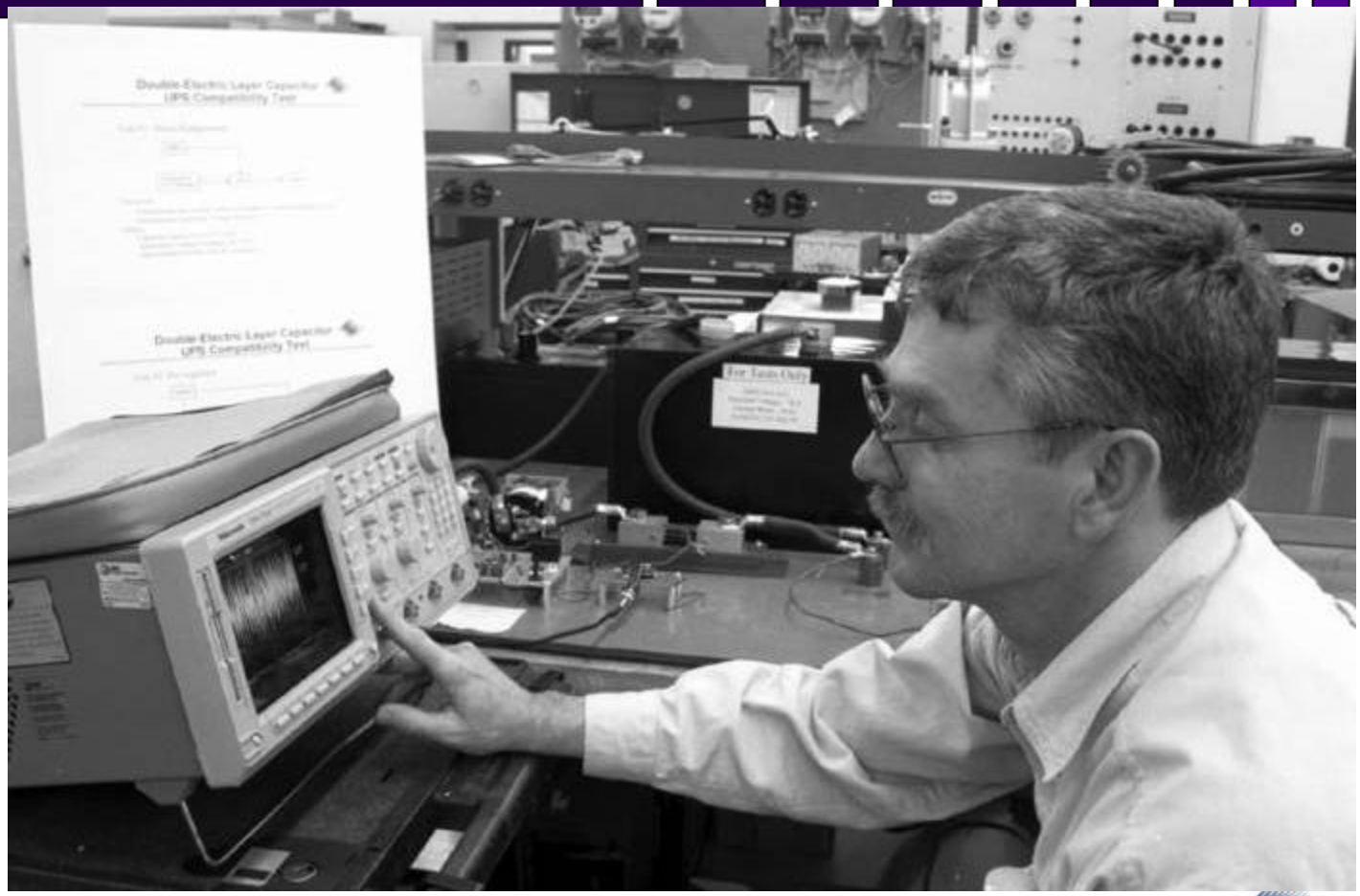
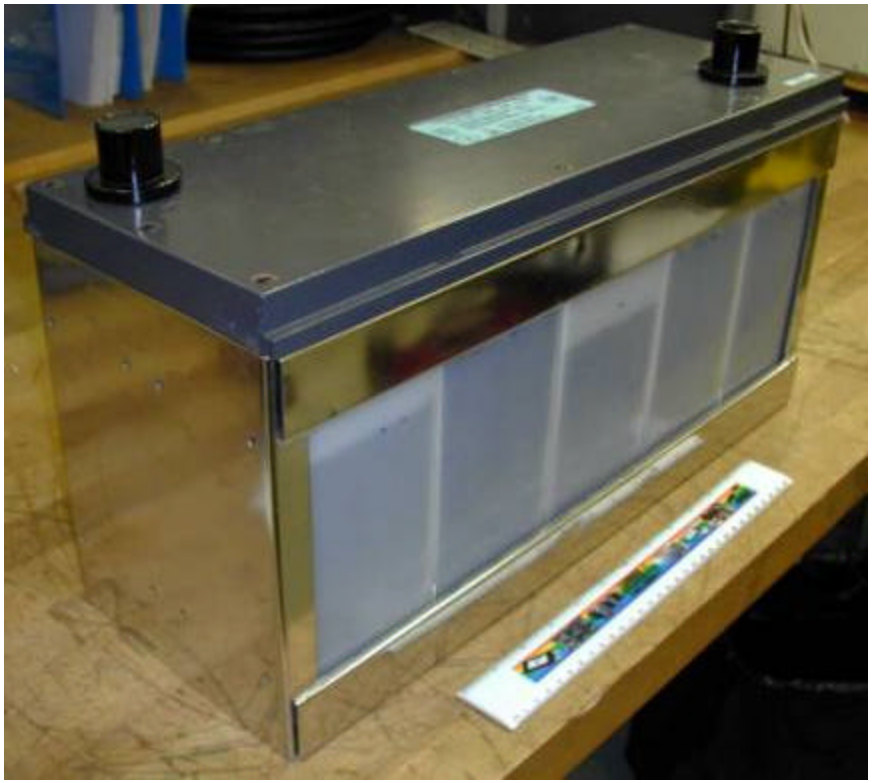
Testing of sample ultra caps



ESMA Ultra Capacitor

- In 1999-2000 PEAC tested several models of asymmetrical supercapacitors. Results confirm manufacturer performance claims.

- For Example ESMA
  - Voltage window 16-8V
  - Stored Energy 1 MJ
  - Weight 75 lbs (34 kg)



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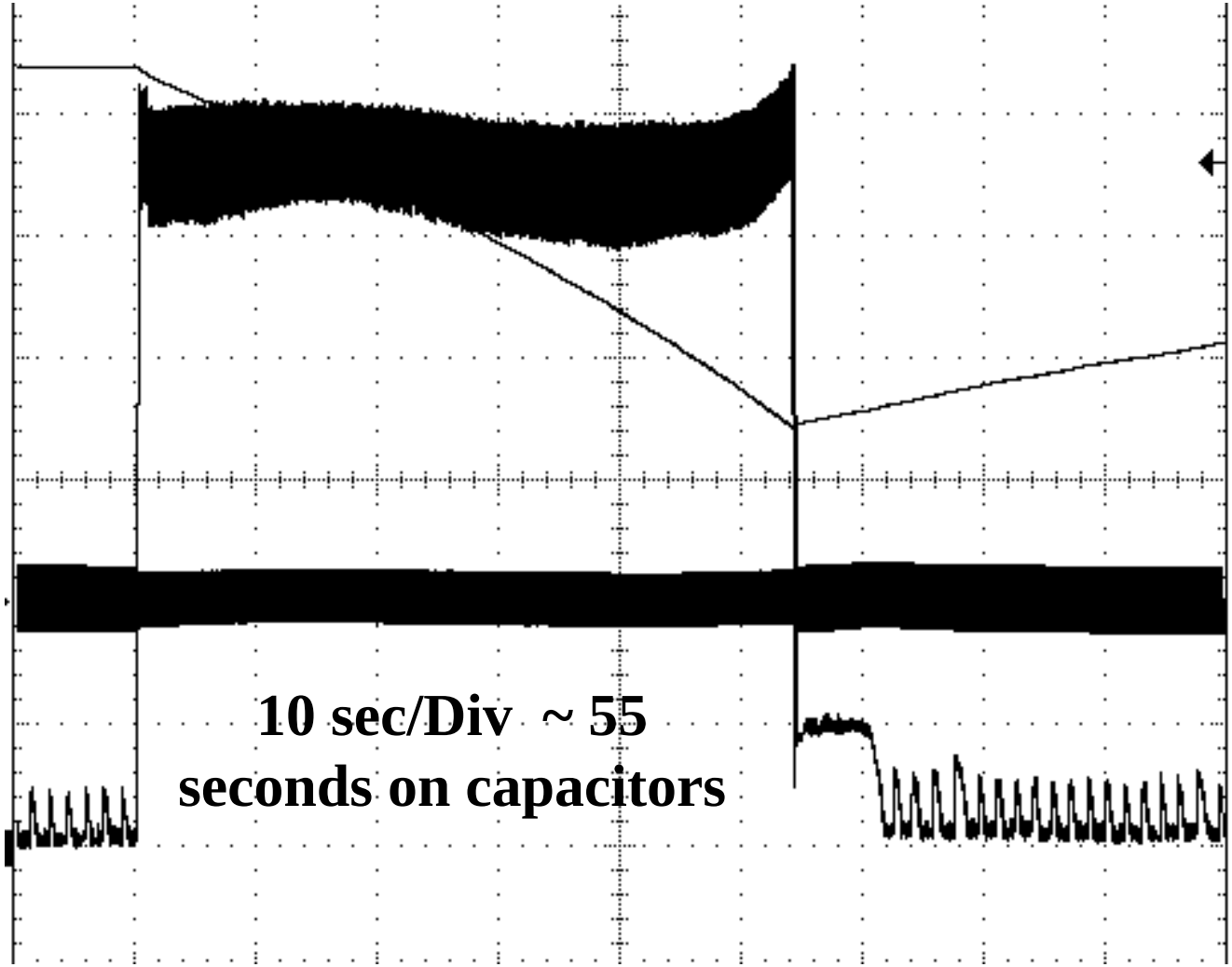
Plot of UPS characteristics with ELIT 110/220PP capacitor

Capacitor Dc Voltage (25V/Div~ 185 Vdc)

UPS Vac Output 120Vac

Capacitor Dc Current 2A /Div~11amps)



Note: No measurable change after 2000 ride-thru cycles

Key Results in Ultra Cap Report

- New asymmetrical design ultra caps have 4 to 10 times greater energy density versus traditional symmetrical designs.
- For stabilizing applications such as hybrid PEM-Ultra Cap and motor starting the ultra cap is a natural partner.
- Fuel cell with ultra-capacitor may have sufficient energy density to replace lead-acid batteries in short duration applications…e.g. in a UPS or ASD, and may be the least cost option in these applications.

Status as of 7/2001

- Completed topical report on double layer electrochemical capacitor technology
- Have mated ESMA ultra capacitors with DCH-Enable 3-kW PEM fuel cell from Enable
- Beginning evaluation of 3-kW hybrid fuel cell-ultra capacitor system

Comparison of Different Energy-Storage Technologies Regarding Peak Power and Specific Energy Characteristics